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## A comparative study of MPPT algorithms to optimal power extraction of a photovoltaic panel

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### Abstract

The demand for electrical energy has been increasing in recent years as well as the constraints related to its production. Thus, more electrical energy will be produced by photovoltaic process which is the conversion of sunlight into electricity because it is inexhaustible energy, developable everywhere, clean and requires little maintenance. The drawbacks of this source of energy are the intermittency of the photovoltaic source and the power supplied by the photovoltaic generator depends on unpredictable meteorological conditions. Among the solutions to remedy this, it is possible to consider the storage of energy in batteries and the implementation of a strategy of the maximum power point tracking (MPPT) to extract at any time the maximum power. Indeed, the improvement of the efficiency of the photovoltaic generator requires optimal operation of the DC-DC converters used as an interface between the photovoltaic generator and the load to be powered. The principle of this control is based on the automatic variation of the duty cycle of the converters by bringing it to the optimal value so as to maximize the power delivered by the photovoltaic module. This work studies and compares the most popular MPPT algorithms. The Perturb and Observe (P&O) algorithm is based on a periodic disturbance of the voltage at the terminals of the photovoltaic module and the comparison of the output power of the photovoltaic module with that of the previous disturbance cycle. The INcremental of Conductance (INC) algorithm uses the knowledge of the conductance value and the increment of conductance to derive the position of the operating point from the point of maximum power. The Hill Climbing (HC) algorithm is based on the duty cycle in each sampling period that is determined by comparing the current power to the previous one. The algorithm for measuring a fraction of the open-circuit voltage (FCO) is based on the linear relationship between the open circuit voltage and the voltage at the peak power point. The algorithm for measuring a short circuit current fraction (FCC) is a technique based on the linear relationship between the short-circuit current and the current at the point of maximum power. Finally, the fuzzy logic control algorithm (FLC) works with inaccurate inputs that do not require a precise mathematical model. All of these techniques have been implemented under the MatLab/Simulink environment to manage the duty cycle. The comparison of the results obtained under different operating conditions shows that the FLC algorithm is the fastest in terms of stabilization time with a response time of 0.005 seconds. It shows good oscillation behavior around the operating point. The latter is followed by the P&O algorithm with a response time of 0.06 seconds, by the INC algorithm with a time of 0.07 seconds, by the Hill Climbing (HC) algorithm with a response time of 0.08 seconds, by the FCC and FCO algorithms with a response time of 0.10 and 0.11 seconds, respectively. The power of the different MPPT algorithms is evaluated at the maximum power point with a 40 W photovoltaic module. The fuzzy logic control algorithm (FLC) gives the best results by extracting 39.8 W, followed by P&O algorithms (38 W), INC (37.5W), HC (36W), FCC (35W) and FCO (34W).

**Keywords:** photovoltaic module, DC-DC converter, maximum power point tracking (MPPT), MPPT algorithms.



## Motivation

The electrical energy produced by photovoltaic (PV) process is inexhaustible, developable everywhere and clean. Whatever the conditions, it is desirable to extract the biggest amount of power from the solar panel. This is achieved with the use of a Maximum Power Point Tracking (MPPT) algorithm.

## Problem

Fluctuations in weather conditions (irradiation and temperature) strongly degrade the performance of the photovoltaic module's energy conversion and therefore all the power can not be transferred to the load.

## Objective

The objective is to study and compare six different approaches of MPPT algorithms to evaluate the power extracted for an experimental platform implementation.

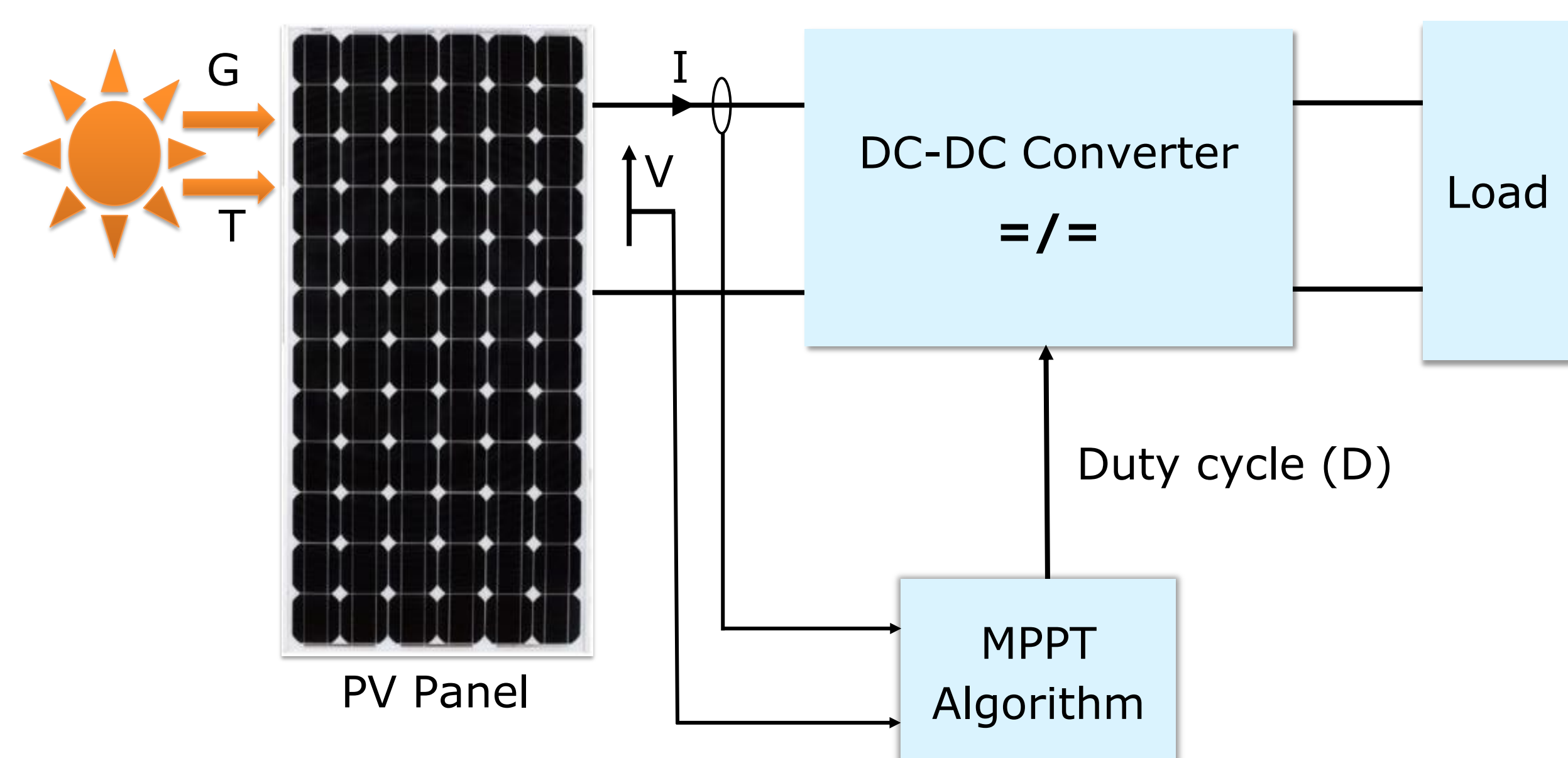
## Solution

A photovoltaic system mainly consists of a PV panel, a DC-DC adaptation stage with a MPPT algorithm and a load as represented by Figure 1.

Indeed, the design of a DC-DC adaptation stage corresponds to the modeling of the basic functions of a DC-DC converter. The latter is achieved by the notion of conservation of the power transferred by a static converter. This power conversion corresponds to the relations between the four electrical quantities on the input and output points which are its currents and its voltages.

The role of the DC-DC converter is to achieve an adaptation between the PV panel and the DC load to have a maximum power transfer.

The operating point is therefore maintained in the vicinity of the Maximum Power Point (PPM) according to the operating conditions.



**Figure 1** : PV system with maximum power point tracking (MPPT)

Here  $G$  is the solar irradiance,  $T$  is the temperature,  $I$  and  $V$  are respectively the current and voltage of the PV panel. The calculation of the duty cycle  $D$  of the converter should optimal whatever the variations of the quantities.

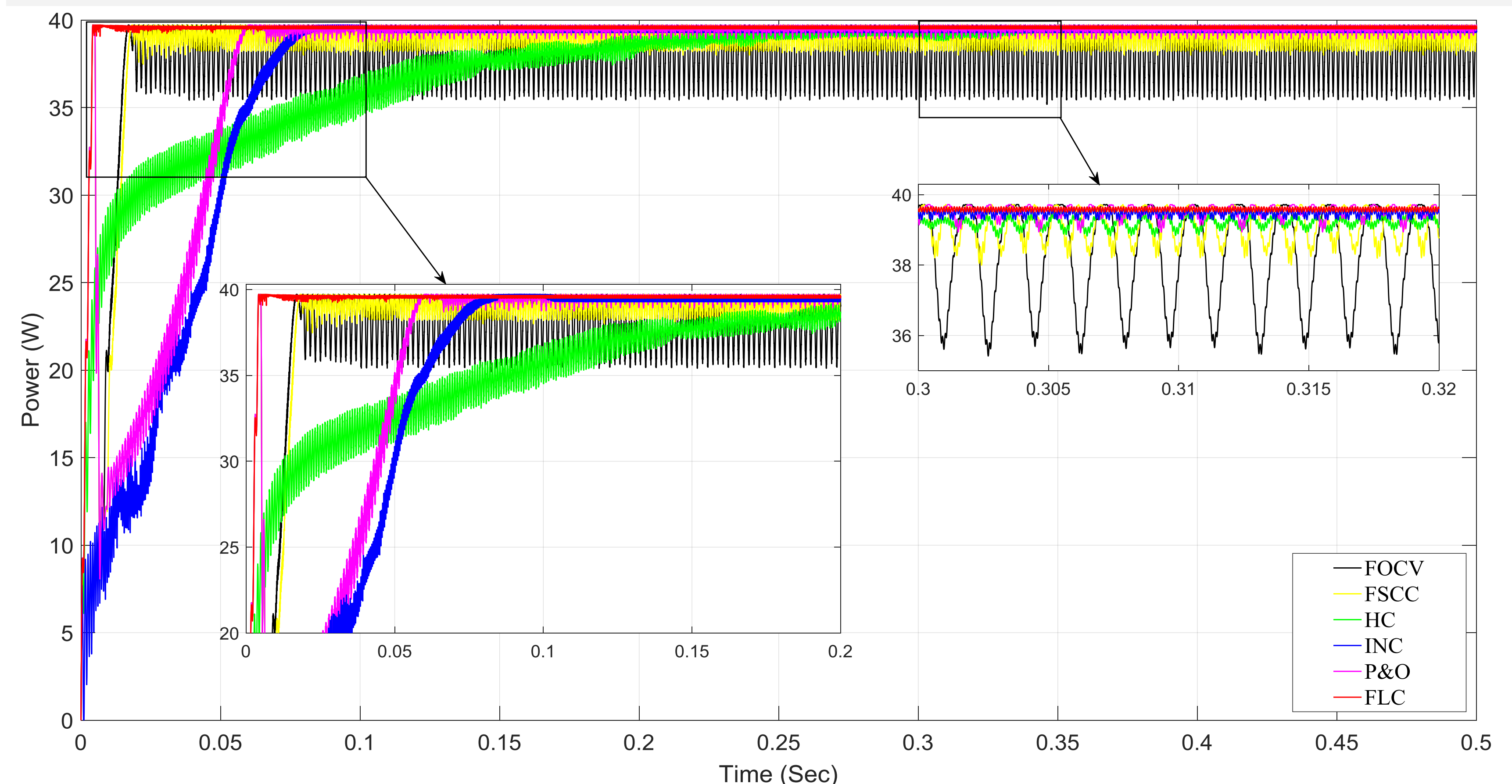
## Description of 6 methods

- ❖ The **Perturb and Observe (P&O)** algorithm is based on a periodic disturbance of the voltage at the photovoltaic module's output and by comparing of this disturbed output power with that of the previous disturbance cycle [1-4].
- ❖ The **INcremental of Conductance (INC)** algorithm uses the conductance value and the increment of the conductance to deduce the position of the next operating point as close as possible to the point of maximum power [1-4].
- ❖ The **Hill Climbing (HC)** algorithm calculates the duty cycle in each sampling period by comparing the current power to the previous one [1-4].
- ❖ The **Fractional Open Circuit Voltage (FOCV)** algorithm is based on a linear relationship between the open circuit voltage and the voltage at the peak power point [2, 4].
- ❖ The **Fractional Short-Circuit Current (FSCC)** algorithm is a technique based on the linear relationship between the short-circuit current and the current at the point of maximum power [2, 4].
- ❖ The **Fuzzy Logic Control (FLC)** algorithm works with inaccurate inputs that do not require a precise mathematical model [1, 2, 4].

## Results

### Case 1: Standard test conditions

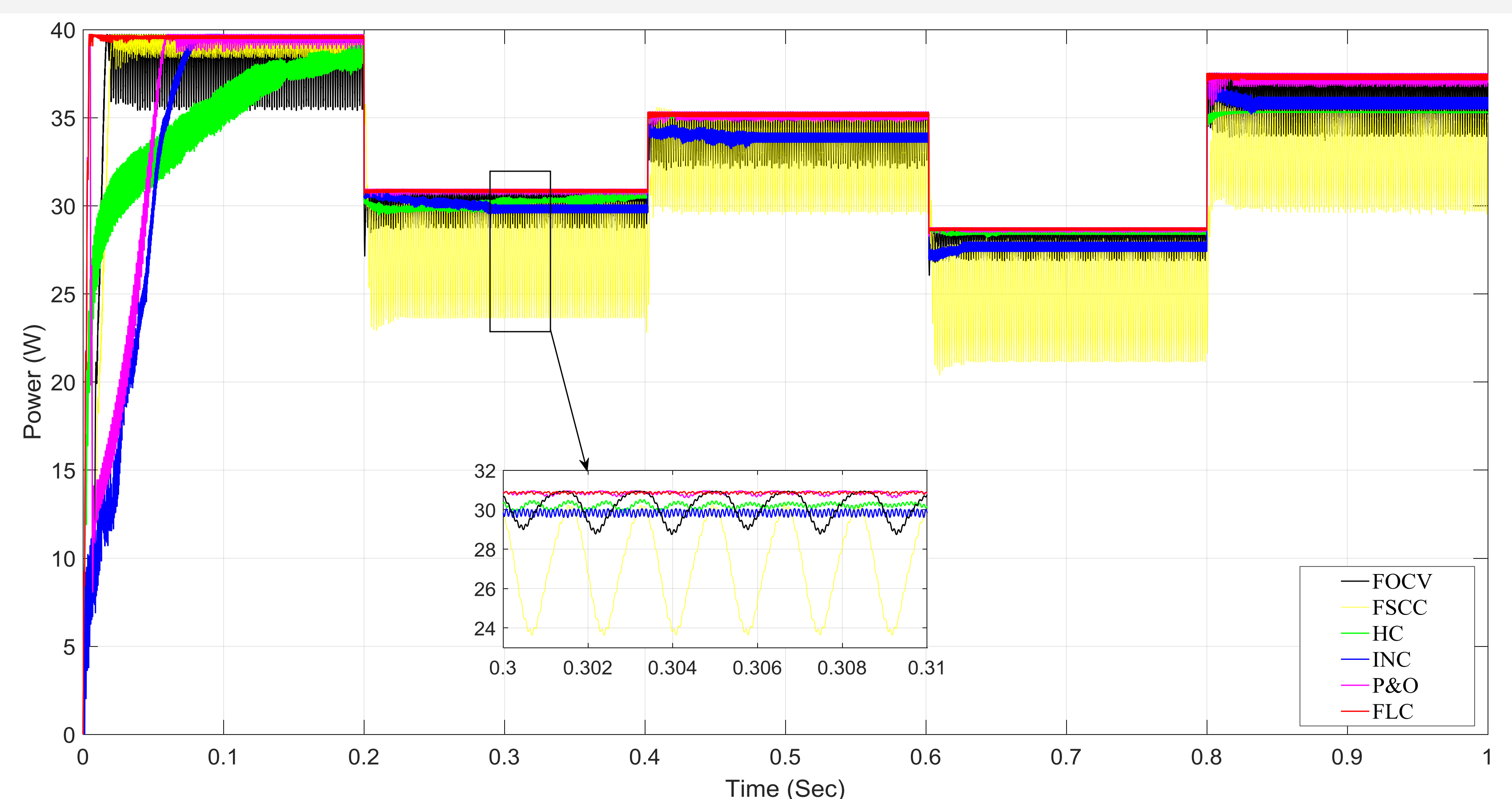
In this case, the six algorithms are evaluated for  $G = 1000 \text{ W/m}^2$  and  $T = 25 \text{ °C}$ . Figure 2 shows the power extracted from the PV panel and delivered to the load with the 6 methods in a simulation test over a duration of 0.5 s.



**Figure 2** : The output power of PV system with the 6 MPPT methods

### Case 2: Changes of the solar irradiance with a constant temperature of 25 °C

Initially,  $G = 1000 \text{ W/m}^2$ , goes to  $800 \text{ W/m}^2$ , rises to  $900 \text{ W/m}^2$  then decreases to  $750 \text{ W/m}^2$  and finally reaches  $950 \text{ W/m}^2$ . Changes in irradiance were made every 0.2 s with a total simulation duration of 1 s.



**Figure 3** : The performance of the different MPPT algorithms

| N° | Algorithms | Response time (s) | Ripple rate (%) | PV output power (W) | Maximum power from the PV (W) | Tracking efficiency (%) |
|----|------------|-------------------|-----------------|---------------------|-------------------------------|-------------------------|
| 1  | FLC        | 0.005             | 0.25            | 39.65               | 40                            | 99,10                   |
| 2  | P&O        | 0.06              | 1.02            | 39.5                | 40                            | 98,75                   |
| 3  | INC        | 0.07              | 1.02            | 39.4                | 40                            | 98,50                   |
| 4  | HC         | 0.15              | 1.27            | 38.5                | 40                            | 96,25                   |
| 5  | FSCC       | 0.02              | 5.26            | 37.5                | 40                            | 93,75                   |
| 6  | FOCV       | 0.02              | 10.81           | 37                  | 40                            | 92,50                   |

**Table 1** : Comparison of different MPPT algorithms

## Discussions

Results with all these algorithms are compared under different operating conditions, the power produced under the standard test conditions is shown in Figure 2. Figure 3 shows a test for varying weather conditions. A summary of the performance indicators of the 6 algorithms is presented in Table 1.

The FLC is the fastest in terms of stabilization and is followed respectively by FSCC, FOCV, P&O, INC and HC algorithms. The FLC also gives the best results in extracting, followed by P&O INC, HC, FSCC and FOCV algorithms.

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